Electro-Thermal-Mechanical Simulation Capability

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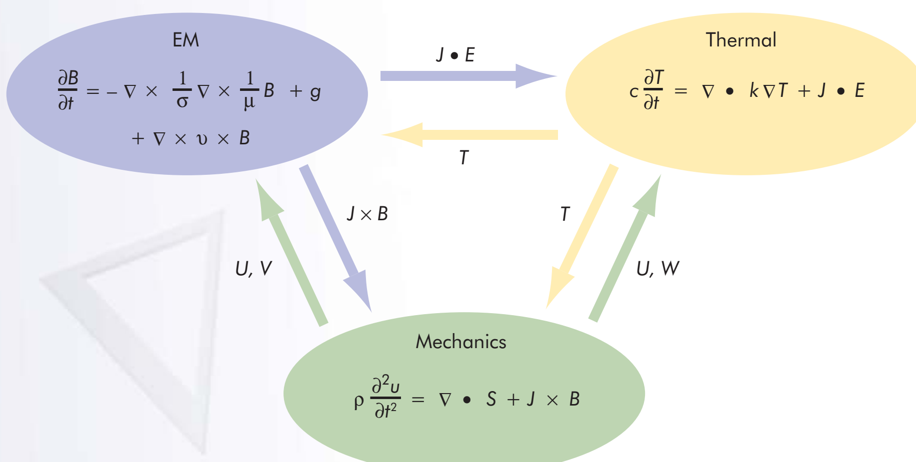
LLNL has long been a world leader in the area of computational mechanics, and recently several mechanics codes have become "multiphysics" codes with the addition of fluid dynamics, heat transfer, and chemistry. However, these multiphysics codes do not incorporate the electromagnetics that is required for a coupled electro-thermal-mechanical (ETM) simulation. There are numerous applications for an ETM simulation capability, such as explosively-driven magnetic flux compressors, electromagnetic launchers, inductive heating and mixing of metals, MEMS, and biophysics.

Project Goals

The purpose of this project is to research and develop numerical algorithms for 3-D ETM simulations. A simplified illustration of the coupling mechanisms is shown in Fig. 1. We will use an *H (curl)*-conforming finite-element method for the electromagnetics equations, and this will be coupled with existing finite-element thermal-mechanics codes, ALE3D and Diablo. Specific research issues that will be addressed include advection of electromagnetic quantities, continuity of electrical quantities in the context of contact, and Green's Function approaches for air/vacuum regions. The product will be a suite of ETM simulation software, designed for large-scale parallel simulation, and compatible with existing LLNL Engineering and DNT code frameworks.

Figure 1. Illustration of the proposed coupling mechanisms. The mechanics module computes the stress, strain, velocity (V), and position (U), of the geometry. The thermal module computes the temperature (T). The electromagnetics module computes the fields and currents, and provides the Joule heating J • E and the magnetic force $J \times B$ to the other modules.



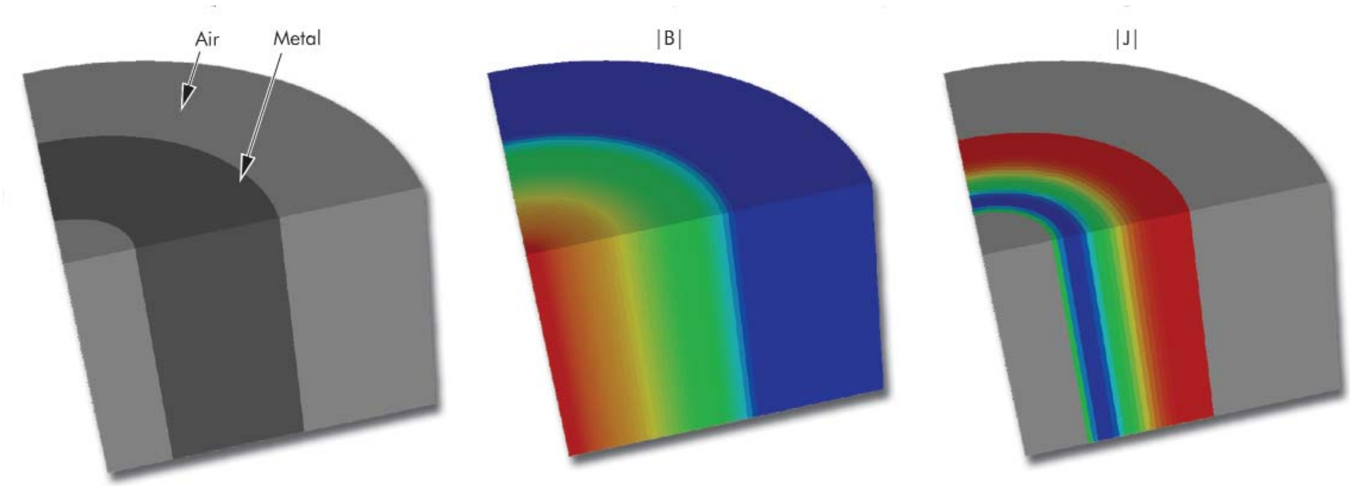


Figure 2. An example problem that has been used to benchmark our prototype finite-element electromagnetic diffusion equation algorithm. The problem consists of a metal cylinder (dark gray), with air (light gray) on the inside and outside. This is a 3-D time-dependent simulation. The middle picture shows a snapshot of the B-field magnitude, and the right picture shows a snapshot of the z-component of the current density. While the computational mesh is 3-D, with appropriate boundary conditions the computed results can be compared to the analytical solution for eddy currents in an infinite metal cylinder.

Relevance to LLNL Mission

Large-scale scientific simulation is a core-competency of LLNL. This project builds upon and enhances our expertise in multiphysics simulations. We will develop a novel simulation capability that is not available commercially, from academia, or from the other national Laboratories. With this capability, LLNL will have an unprecedented ability to simulate, design, and optimize ETM systems. A robust ETM simulation capability will enable LLNL physicists and engineers to better support current DOE pulse-power programs, as well as future programs, and will prepare LLNL for exciting long-term DoD opportunities.

FY2004 Accomplishments and Results

This project started in mid-FY2004. We are currently investigating different finite-element formulations for the electromagnetics equations, *i.e*. field-based vs. potential-based formulations. While the ultimate goal is to develop a simulation for dynamic (moving, deforming) geometry, we are currently evaluating alternative formulations in the context of motionless geometry, since there are numerous benchmark solutions that can be used as metrics.

In Fig. 2 we show a preliminary simulation of a 3-D eddy current problem. In the eddy current problem, a time-varying magnetic field diffuses into a conductor and induces electrical currents, which in turn generate an induced magnetic field. This particular example is of a finite metal cylinder, with the external magnetic field due to a current on the z-axis. This simulation uses an *H (curl)*-conforming finite-element discretization of the *E*-field vector diffusion equation, with implicit Crank-Nicholson time stepping. The *H (curl)*-conforming discretization properly models the discontinuity of fields and currents across material interfaces, and also maintains the divergence-free character of the fields and currents.

FY2005 Proposed Work

In FY2005 we will continue to research finite-element discretization methods for electromagnetics. We will evaluate an *E*-field formulation, an *H*-field formulation, and an *A*-field formulation. For each formulation an *H (curl)* finite element discretization will be used and the same Crank-Nicholson time stepping can be used. The difference in these formulations is manifested in different source terms and boundary conditions. We will develop a software module that can be incorporated into both the Diablo and ALE3D codes. Coupling the electromagnetics with the mechanics is the primary task for FY2005. We will also begin to research issues associated with advection, dynamic contact, and air/vacuum regions.